GANGRENE: Exploring the Mortality of Flash Memory

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Flash memory is ubiquitous
Flash memory is ubiquitous
Flash memory is fast, rugged, and cheap
...but flash memory has a weakness
finite write endurance

“depletable storage” – both capacity and write endurance are limited constraints,
Prabhakaran (HOTSTORAGE 2010)
Various strategies are used to increase flash endurance:

- Wear-leveling
- Deduplication
- Error correction codes

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Flash controllers employ these strategies and manage flash

- Flash controllers use strategies like Flash Translation Layer (FTL), RAM, and algorithms (Wear Leveling, Garbage Collection, compression, deduplication, etc).

- Interfaces include USB/SAS/SATA and communication to flash IC.
Flash memory is generally tested under “normal” use.
GANGRENE seeks to induce premature death of flash

Goals:

– maximally accelerate wear
– attack with no a priori knowledge
– passively evade detection
What is the meaning of LIFE?

\[
LIFE = \frac{C \times E_{max}}{A}
\]

\(LIFE\) – device life expressed in GB written
\(C\) – published device capacity in GB
\(E_{max}\) – rated PE cycles (vendor provided)
\(A\) – acceleration factor (\(LIFE\) is reduced for \(A > 1\))
What is the meaning of LIFE?

**Example**

2GB device with endurance rating of 3,000 cycles dies after 600 GB are written:

\[
A = \frac{C \times E_{\text{max}}}{\text{LIFE}} = \frac{2 \text{ GB} \times 3,000}{600 \text{ GB}} = 10
\]

This device experienced a 10x acceleration in degradation.
We implemented GANGRENE

GANGRENE in C
maximize write activity
vary file size
vary file contents
log and monitor throughput
wait...
For our random protocol we observed a mean acceleration of 15.94

\[
\mu_A = 15.94 \quad \sigma_A = 7.71
\]

<table>
<thead>
<tr>
<th>Drive #</th>
<th>C (GB)</th>
<th>(E_{\text{max}})</th>
<th>LIFE (GB)</th>
<th>(A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3,000</td>
<td>204.6</td>
<td>29.33</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>3,000</td>
<td>414.9</td>
<td>14.46</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>3,000</td>
<td>450.2</td>
<td>13.33</td>
</tr>
<tr>
<td>4</td>
<td>2</td>
<td>3,000</td>
<td>627.1</td>
<td>9.57</td>
</tr>
<tr>
<td>5</td>
<td>2</td>
<td>3,000</td>
<td>461.5</td>
<td>13.00</td>
</tr>
</tbody>
</table>

These drives failed in 14-29 days
These results are ‘out of the box’ (no tuning)
For our test drives we observed a mean acceleration of 15.94

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<tr>
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<th>C (GB)</th>
<th>$E_{max}$</th>
<th>$A$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>204.6</td>
<td>2,300</td>
<td>29.33</td>
<td></td>
</tr>
<tr>
<td>2</td>
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no failures from the deterministic protocol drives after 6 months!

still going...
What is death like?

- denial to write
- failure may preserve existing data
- failure is not always permanent
- failure occurs with no warning
What about other flash devices?
What about other flash devices?
What about other flash devices?
Can GANGRENE do better?

• we still know very little about flash vulnerability
• can $A$ be increased?
• more testing is necessary
How can we defend against GANGRENE?
How can we defend against GANGRENE?

- Host system
  - Application
  - Operating system
  - Driver
- Flash device
  - Flash memory IC
  - Flash controller IC

- Interface
- Monitor I/O use
- Display
- Detect

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How can we defend against GANGRENE?

visibility of wear

fine-grained write control
How can we defend against GANGRENE?

don’t be write promiscuous
More work is needed to bolster flash devices against malicious use

• we rely on many devices that use flash memory
• our results show that failure occurs completely and without warning
• are SSDs and mobile devices vulnerable to GANGRENE?